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TITLE- Operations and Maintenance Subsequence for a Multi-Disciplinary Earth Orbital Space Station

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AUTHOR(S)- S.L. Penn

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ABSTRACT

To permit maximum crew attention to achievement of technical objectives of a manned, multi-disciplinary space station, control of the operational systems is automated during experiment performance parts of the mission. System performance monitoring and fault detection are also automated, with occasional, additional manual checks and inspections. The key role of man in the Operations and Maintenance (O&M) Subsequence is the performance of unscheduled, contingency based component replacement and repair, to provide long lived, reliable operation of the space station. The factors that cause transitions from one O&M mode or activity to another are described in terms of degree of criticality or risk, and the modes are presented in tabular format for convenient analysis.

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X69-75540

I. INTRODUCTION

A concept is presented for operating and maintaining a manned, multi-disciplinary space station for up to two years in an earth orbit with an altitude of about 270 nautical miles. This is one of several related studies by co-workers and the author to see whether such a station can be both feasible and productive. The disciplines, in their separate studies, are thought of as subsequences, so that their time phased performances can be coordinated in an overall mission sequence plan, as is being done concurrently in Reference 1.

The approach herein is to make engineering judgements as to how such a station should be run and to estimate and examine the probable consequences of acting in accordance with these judgements. It is hoped that feasibility and reasonableness will become evident. Optimization, if desired, would be left to succeeding investigations.

II. DEFINITIONS

Operations is ordinarily thought of as the whole body of activities and procedures, manned and automated, necessary to perform a mission. In this context, space operations would include flying and maintaining the spacecraft, living in it, and performing useful work in it. Maintenance, as a subpart of operations, would entail the service and repair necessary to keep things functional.

For the assumed multi-disciplinary mission, operations is defined in a more limited way. Experiment and personal activities are not included, since they are the subjects of the other, earlier mentioned studies. Maneuvering, habitability preparations, and logistics resupply are not treated at all because they don't occur in the experiment performance parts of the mission, which are the primary periods of interest. Maneuvering, during these periods, is avoided by attaching experiment groups that require pointing to gimballed platforms.

Maintenance has much the same meaning as in general usage, but more than the usual significance. Provision of a capability to perform maintenance when anticipated but unscheduled breakdowns occur is the assumed approach to extended and reliable manned flights. These contingency caused replacements and repairs are performed on a timely basis, consistent with the degree of risk and schedule impact. While scheduled maintenance must also be provided, it would be advantageous to plan for major routine service to take place at logistic resupply time (about every 90 days for the assumed mission), for minimum interference with the regular experiment program.* One exception may be molecular sieve bakeout about every six days, as expected for a crew of six in a workshop size space station. Less significant, but more frequent servicing, such as routine cleaning, is included in the housekeeping sessions of the subsequence on personal maintenance.

Since hardware in each of the experiment disciplines may require maintenance, service and repair of their componentry are made the responsibility of the concerned disciplines. Major maintenance on the whole system level and all maintenance of operational equipment is performed as part of this subsequence. The statistics of the combined maintenance requirements are treated herein and in Reference 1.

III. ASSUMPTIONS

The vehicle configuration which serves as our baseline is the Saturn V, B-2 Workshop(2). The borrowed assumptions relevant to this study are the approximate 270 nautical mile orbital altitude, the independent experiment pointing, the 90 day resupply cycle, the minimization of EVA requirements, and the provision of redundancy to safety critical features, to prevent crippling by a single emergency or failure. While these assumptions are convenient and plausible, they were chosen more to provide a framework than a limitation to our analysis. Since EVA is not expected to be needed for operational purposes, any requirement for and discussion of it is left to the investigators of those other disciplines which may have an interest.

IV. BACKGROUND AND PHILOSOPHY

A number of studies have been made of both general and specific aspects of space station operations and maintenance. Ong, in his review and analysis of operations on long duration manned missions,(3) presents three basic modes which operations can take--a watch mode of 24 hour attention to operations; an alert mode, with someone alert to operational needs even if assigned to other activities; and a sleep mode, with everyone asleep at once.

*With up to several days of crew overlap expected and with equipment interchange taking place, available manpower and reduced experiment operation make the resupply period seem well suited to service activities.

These represent various degrees of crew attention, and are examined to see whether differences exist between them in the degree to which the crew is prepared to respond to hazards. He points out that the differences in response times between these modes are small compared to expected repair times and will probably not be significant from a safety standpoint.

Reference 4, Boeing Company, July 1967, is typical of the general studies of maintenance and has an excellent list of references, including summaries of a number of them. The main items of interest from the Boeing study, whose station size and configuration are on the same order as our own, are the estimates of the mean time between failures (MTBF) for all subsystems, considered together, of 6.8 days, the average repair time of 2-1/2 hours, and the completion of 50% of the repairs in less than 70 minutes. A more current (October 1968) summary of a similar study by Boeing [(5)] has almost identical results. S.L. Penn, in Reference 1, derives a MTBF for our space station of 7.0 days. The reference on which this was based was a Garrett study[(6)] of the maintainability of an environmental control/life support system and its fault detection system. Also, that study indicated that the average repair (of the component replacement type, which most repairs should be) can be effected within one hour. This shorter time is supported by a Lockheed study[(7)], also of a life support system. However, even if longer average repair times are necessary, and the occurrence of failures is still on the order of no more than one per week, repairs could be comfortably completed if allowed down times are substantially greater than two hours, which is generally expected. If time for leisurely repair is not available, some suspension of experiment or personal activity will be necessary, but will not cause too much inconvenience due to the long interval between repairs.

For this study, we assume that a practical way to run a space station is with automatic performance of the operational functions and with automatic system monitoring and fault detection. We decide instinctively, however, to provide backup manual monitoring and inspection, three times a day for about one hour each time. (This anticipates an inability to automatically detect every kind of anomaly that may occur, allows for the element of human frailty in the design of the system, and provides increased confidence in our ability to detect anticipated anomalies). That is, we operate for seven hours in a completely automatic mode, with no one paying attention to or on particular alert for operational matters, and then in a modified watch mode for the next hour (modified in the sense that a regular watch entails full time devotion to operations). This kind of operations scheme will allow the maximum crew attention to the more technically productive tasks for which the mission is intended.

V. HARDWARE

Assumed operations and maintenance systems and hardware and some of their functions are listed below. While they may bear on the role of the crew to varying degrees, they are presented here more to provide insight as to the scope of the subject discipline than to define limitations on the crew role or operational procedures.

Spacecraft

Two year, dry launch, six-man station.

Environmental Control/Life Support System (EC/LSS)

Automatically provides atmospheric gases, humidity and temperature control, and contaminant removal. Molecular sieve CO_2 removal seems likely.

Electrical Power System (EPS)

Automatically provides power required by other operational systems and by experiments up to ten kilowatts. Probably use solar cells and storage batteries.

Data Management System (DMS)

Provides recording capability for operational and experiment parameters up to 2.5×10^5 to 2×10^7 bits per second (to be decided). Also provides interfaces between data generating, using, and communications systems.

Communication System

Provides transmission and reception capability for operational and experiment purposes up to 2×10^7 bits per second during ground station passes. Uses uprated Apollo and Manned Space Flight Network. Does not count on Data Relay Satellite System, though presence of latter could reduce peak requirements or increase total data transmitted.

Attitude Control System (ACS)

Provides whole-vehicle orientation and stability. Uses control moment gyros during experiment performance period, for fuel conservation and to avoid interference with optical experiments. Latter would be separately gimbaled for pointing, if vehicle orientation was fixed, as suggested in reference 2 (which has long axis in orbital plane and yaw axis pointed toward sun).

Automatic On-Board System Monitor (AOBSM)

Automatically checks system performance and warns of malfunctions and danger. Has anomaly detectors, parameter displays, and alarms.

On-Board Computer (OBC)

Handles requirements of DMS and AOBSM for computations and storage of paramater reference data. Provides timeline assistance and experiment control logic.

Replacement Components and Tools

Sufficient to provide some large but reasonable probability of mission success, based on a resupply period of 180 days (double that expected).

VI. Subsequence Description

Figure 1 is a tabular presentation of the modes of the Operations and Maintenance Subsequence. The modes are described in terms of their frequency, duration, crew men required, activities, information required and generated, power and other resource requirements, and transition factors, which cause the changes from one mode to another. Nominal activities are covered by three modes--Automatic, Modified Watch, and Service--and off-nominal by five--Watch, Repair (Unsuited), Repair (Suited), Standby, and Abort. The nominal modes are a consequence of the mission philosophy discussed earlier. Operation in the Automatic mode (A) is adequately covered by previous discussion and Figure 1.

The scheduling of the Modified Watch mode (B) can be more flexible than shown; for instance, performance once during each eight hour shift should be sufficient as long as no more than, say, twelve hours separates the repetitions. As the mission progresses, confidence in the AOBSM, based on experience, may increase and warrant reducing the performance of this mode to only once per day.

For those few major servicings that are necessary more frequently than every 90 days, the Service mode (C) would be implemented. This would be in addition to whichever of the other two nominal modes was in progress, though effort should be made to avoid coincidence with mode B, due to the need for at least one crewman in each of C and B. Hopefully, most servicing can be programmed to occur only at resupply time. Minor, housekeeping servicing would be done in Personal Maintenance, as mentioned earlier.

VII. CONTINGENCY ANALYSIS

Transitions to off-nominal modes result from the occurrence of contingencies, whose incidence will depend on the chosen reliability and maintenance goals and methods. The writer has not examined the problem in depth, but some of the alternatives seen and their consequences are as follows:

1. Make all parts sufficiently reliable to preclude failure during the mission.--Too expensive and time consuming.

2. Make all potential fail points redundant. Repair a failed part while the other takes over.-- Requires excessive redundancy.

3. Only make redundant those parts whose failure would not allow sufficient repair time to prevent EC/LSS parameters from exceeding nominal (or allowed) bounds, i.e., safety critical items.--To do this we must have advance knowledge of the failure mechanisms, times to repair, and effects of failures on systems and crew. This leaves little room for error (must identify all safety critical points) and requires considerable advance work and analysis, but it makes the minimum demands on final system hardware in terms of redundancy and, hence, weight and volume.

The latter philosophy has been adopted for this mission. Not only does it reduce redundancy to a reasonable minimum, but it also provides flexibility to the scheduling of repairs, since potentially dangerous malfunctions have been identified and guarded against with redundancy.

Ideally, every repair would have a priority that could be weighted against the priorities of other tasks to see which get performed first. The repair priority could be a function of a changing safety relationship with time, or could relate to the risk of data loss in a concerned experiment. While the simplest approach would be to make every repair as soon as the malfunction is identified (Due to the once a week occurrence, pointed out earlier, this might not be too unreasonable.), as a practical matter, where the risk is known to be small, repairs can be delayed to more convenient times, expecially if immediate performance would cause a schedule impact.

When a contingency occurs, its criticality (degree of hazard) will determine the off-nominal mode selected. The criticality levels used in Figure 1 are:

Criticality 1 - Environment parameter exceeding nominal limits, but not danger limits or acceptable danger approach rates.

Criticality 2 - Environment anomaly approaching level of danger to unsuited astronauts, with no immediate threat otherwise and with time to don suits.

Criticality 3 - Immediate threat with time only for retreat to CM/SM, but not requiring immediate abort (e.g., major fire or meteor penetration).

Criticality 4 - Immediate threat requiring earliest possible abort (e.g., explosion, destruction, or disruption of vehicle not unlikely).

These definitions follow and are consistent with the particular contingency modes defined for the subject mission. For this reason they do not correspond precisely with Apollo and AAP caution and warning criteria. Typical contingencies, besides component failures, that might warrant a transition to one of the off-nominal modes, are listed in a table in the author's concurrent memo on mission sequence planning(1). They include uncontrolled spin, plumbing leakage, meteor puncture, fire, radiation hazard, atmospheric contamination, etc.

Regarding the off-nominal modes themselves, the following may be noted:

Watch Mode - This is strictly a contingency mode for this mission, since it would impact the planned activities of other disciplines through a reduction in available manpower. It is used only when the AOBSM is suspect.

Repair (Unsuited) - This is the common repair mode, occurring on the average about once a week. Most malfunctions, being of the component failure type, should not cause environment anomalies due to the redundancy policy for safety critical items.

Repair (Suited) - Probable causes for going to this mode would be low expectancy events such as meteor puncture, fire, or simultaneous failure of redundant parts of a safety critical system. The assumed MTBF of one year is an intuitive guess, intended to give a frequency reasonably less than that of unsuited repair, but not so small as to be disregarded (because we sense that the frequency and, certainly, the impact are not negligible). Experiment activity in this mode would almost certainly be suspended. While Figure 1 shows all men suited in this mode, if the men not involved in the repair could retreat to a separable, self-supportable part of the station, they might not have to suit up. This would extend the time that portable (individual) life support systems (PLSS's) would be available for repair activity.

Standby - In the event of an emergency which didn't require earliest possible abort, the crew would retreat to the Command Module and try to remotely analyze the problem and devise a solution. If no reasonable hope of salvaging the mission or station were found, the crew would then abort.

Abort - While usually an emergency escape procedure, abort might not always require maximum haste. For example, crew illness or injury may have caused the decision to abort, and steps would first have to be taken to assure the maximum comfort of the disabled persons for the re-entry and landing.

VIII. SUMMARY AND CONCLUSIONS

A methodology for thinking about and analyzing space station operations and maintenance has been presented. The environmental and other operational systems would be automatically controlled during the experiment performance parts of the mission. Monitoring of system performance and fault detection would be basically automated, with occasional manual checks and inspections. If major servicing were necessary, where possible it would be scheduled to occur at resupply time, to avoid conflict with experiments. Unscheduled maintenance - principally component replacement as malfunctions occur - would be the key to long term, reliable performance.

We conclude that the suggested modes of operations and maintenance, with their low demands on crew time, offer a feasible and practical way of running a space station.

S. L. Penn

1011-SLP-bl S.L. Penn

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5. Jennings, H.A., "Reliability and Maintainability Analysis of a Two Year Manned Spacecraft Mission," AIAA Paper No 68-1059, AIAA Fifth Annual Meeting and Technical Display, October 21-24, 1968.

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PROPERTIES \ MODES	A. ACTIVE	B. INACTIVE	C. EVA	D. REPAIR	E. MODIFIED ACTIVE
I. TIME : a) DURATION, REPETITIONS USE OF CREW b) CONSTRAINTS	a) EACH MAN IS A SUBJECT FOR 1-3/4 HOURS/ DAY (AVERAGE) AND AN OBSERVER FOR 3/4 HOUR/ DAY. LAB TECHNICIANS ANALYZE SAMPLES FOR 2-1/2 HOURS/DAY. ANALYSIS TIME CAN BE DIVIDED AMONG THREE SHIFTS b) 1. AVOID STRENOUS EXERCISE WITHIN 2 HOURS FOLLOWING MEALS b) 2. SHOULD BE SCHEDULED WHEN FOUR MEN ARE AVAILABLE FOR WORK (MODE B OF P.M. SUBSEQUENCE.)	14 HOURS/DAY IN 3 PARTS SEPARATED BY THREE MEDICAL WORK PERIODS PER DAY.	a) DURATION IS FOUR HOURS FOR EVA (INCLUDING PREPARATIONS). EACH MAN GOES AT LEAST ONCE, PREFERABLY EARLY IN MISSION. b) AVOID SOUTH ATLANTIC ANOMALY. DEFINITELY LESS THAN ONE EVA/DAY/ MAN, PREFERABLY LESS THAN ONCE/ WEEK.	a) DURATION AND FREQUENCY SAME AS "OPERATIONS AND MAINTENANCE" CHART b) REMOVE BIOELECTRIC SENSORS BEFORE REPAIRING IMBLMS	a) ONLY ONE MAN IS A SUBJECT DURING THIS PERIOD, SINCE HIS BUDDY IS SICK. THE OTHER NON-SCHEDULED CREWMEN FILL IN AS OBSERVER AND LAB TECHNICIAN. b) 1. IF SICK MAN NEEDS PHYSICIAN'S FREQUENT ATTENTION, CREW SHIFTS SCHEDULE SO THAT PHYSICIAN BECOMES SICK MAN'S BUDDY. 2. IF SICK MAN NEEDS CONTINUOUS ATTENTION FOR MORE THAN TWO (?) DAYS, REMAINING CREW MEMBERS CHANGE SHIFTS SO THAT BUDDY CAN PARTICIPATE IN MEDICAL EXPERIMENTS AND BE RELIEVED OF MEDICAL WATCH.
II. ACTIONS AND FUNCTIONS : AGENTS : 1. SUBJECT (SUBJ.) 2. OBSERVER (OBS.) 3. REMAINING AVAILABLE CREW (CREW) 4. INTEGRATED MEDICAL AND BEHAVIORAL LABORATORY MEASUREMENT SYSTEM (IMBLMS) 5. MISSION CONTROL CENTER (MCC)	SUBJ. AND OBS. SET UP AND PERFORM EXPERIMENT OBS. USES IMBLMS AND LOG BOOK, VERIFYING PROPER RECORDING. IMBLMS RECORDS DATA ON TAPE AND PERFORMS COMPUTATIONS. MCC IS USED IN REAL-TIME ONLY IN CONTINGENCIES.	IMBLMS IN STANDBY	SUBJ. AND OBS. PERFORM TASKS, ONE SUITED MAN STANDS BY, FOURTH MAN TALKS WITH MCC, SUBJ., OBS., AND MONITORS LIFE-SUPPORT EQUIPMENT. MCC MONITORS ACTIVITIES AND SYSTEMS.	MEDICAL EXPERIMENTS TERMINATED DURING REPAIR OF IMBLMS. SAME ACTIVITIES AS "REPAIR" MODE OF "OPERATIONS AND MAINTENANCE" (O & M) SUBSEQUENCE.	SAME ACTIVITIES AS IN A, EXCEPT THAT NON-SCHEDULED CREW FUNCTIONS AS AN OBSERVER AND TECHNICIAN
III. INFORMATION FLOW : a) INFORMATION REQUIRED b) ACTIVE LINKS c) DATA PRODUCED : 1) FILM (TYPE, # FRAMES OR FEET, WEIGHT TO BE RETURNED QUARTERLY 2) TAPE (BIT RATES-MAX. SUSTAINED PEAK, AVG; SPECIAL DUMP REQUIREMENTS 3) REALTIME TRANSMISSION	a) 1. PHYSIOLOGICAL PARAMETERS AS REQUIRED BY BY THE EXPERIMENT a) 2. ENVIRONMENTAL PARAMETERS OF CABIN b) MCC-OWS c) 1. UP TO 30 LB. FILM MAGAZINE PER 30 DAYS OF FLIGHT c) 2. MAX. SUSTAINED BIT RATE = 100 KBS c) 3. OCCASIONAL ECG AND VOICE	NONE	a) MEDICAL DATA, VOICE COMMUNICATION, PHOTOGRAPHS, SUIT PARAMETERS. b) VOICE LINKS BETWEEN TWO EVA MEN (NOT INDIRECTLY THROUGH UMBILICALS CONNECTED TO SPACECRAFT), BETWEEN EACH EVA MAN AND OWS, AND BETWEEN OWS AND MCC. BIOMEDICAL DATA TO IMBLMS. c) FILM OF S/C EXTERIOR, METEOROID PLATES, MEDICAL SAMPLES FROM MEN, IMBLMS TAPE, REAL TIME TRANSMISSION, ETC.	AS IN O & M REPAIR MODE	AS IN MODE A
IV. RESOURCES REQUIRED : a) POWER b) OTHER (BESIDES ORDINARY CONSUMABLES)	a) 125 WATTS STANBY, 520 WATTS NOMINAL, 700-1000 WATTS PEAK (MAX. OF 1/3 OPERATING TIME) OPERATING TIME IS 10 HOURS/DAY b) NONE	a) 125 WATTS	a) 30 WATTS TO OPERATE PLSS b) O_2 CONSUMED : 0.7 LBS/HR. MAX.	AS IN O & M REPAIR MODE	AS IN MODE A
V. TRANSITIONS a) SCHEDULED (NOMINAL) b) UNSCHEDULED (CONTINGENCIES)	a) 1. WHEN EXPERIMENTS ARE FINISHED, GO TO MODE B 2. IF AN ASTRONAUT HAS BEEN IN EARTH ORBIT FOR X DAYS BEFORE THIS MISSION, HE NEEDS MORE MEDICAL EXPERIMENT TIME AS A SUBJECT AFTER THE FIRST X DAYS OF THIS MISSION. SEE TEXT b) 1. IF DECONDITIONING OR ILLNESS OCCURS, GO TO E 2. IF IMBLMS MALFUNCTIONS GO TO D	a) 1. GO TO A WHEN MEDICAL EXPERIMENTS ARE SCHEDULED 2. GO TO C WHEN EVA IS SCHEDULED	a) WHEN EVA IS FINISHED, GO TO MODE B. b) 1. IF LIFE-SUPPORT SYSTEM IS DAMAGED SLIGHTLY, STOP EVA TASKS AND INGRESS. 2. IF MAN IS INCAPACITATED, RESCUE HIM. 3. IF EVA MAN IS NEEDED FOR ACTIVITY INSIDE, STOP EVA TASKS AND INGRESS.	WHEN REPAIR IS VERIFIED, GO TO A OR B AS APPROPRIATE	a) UNSCHEDULED b) WHEN INCAPACITATED MAN IS CURED, TO A OR B AS APPROPRIATE

FIGURE 2 - BIOMEDICAL/BEHAVIORAL SUBSEQUENCE OF ACTIVITIES